A CRIMINAL CASE STUDY INVOLVING TRANSFERENCE OF ACID SULFATE SOIL MATERIAL FROM A CRIME SCENE TO FORENSIC EVIDENCE

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CHAPTER 8

A CRIMINAL CASE STUDY INVOLVING TRANSFERENCE OF ACID SULFATE SOIL MATERIAL FROM A CRIME SCENE TO FORENSIC EVIDENCE

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INTRODUCTION

Forensic soil science is the science or study of soil that involves the application of soil science, especially studies that involve soil morphology, soil mapping (assisted by existing soil maps and spatially held soil data), mineralogy, chemistry, geophysics, biology and molecular biology to answer forensic legal questions, problems or hypotheses (Fitzpatrick 2009). Soil science is the term commonly used to study soil as a natural body in the landscape and as a resource to be managed for agricultural production, environmental waste disposal and construction. Forensic soil science is a relatively new activity that is strongly "method-orientated" because it is mostly a technique-driven activity in the multidisciplinary areas of pedology, geochemistry, mineralogy, molecular biology, geophysics, archaeology and forensic science. Consequently, it does not have a large number of past practitioners such as in the older forensic disciplines such as chemistry and physics. These days, "forensic soil science" as a newly developed discipline of soil science has matured to the extent that well-defined questions and successful crime scene investigations can be answered in increasingly refined ways (Fitzpatrick 2008, 2009; Fitzpatrick *et al* 2008).

Forensic soil scientists (or forensic geologists) are more specifically concerned with soils that have been disturbed or moved (usually by human activity), sometimes comparing them to natural soils, or matching them with soil databases, to help locate the scene of crimes. Forensic soil scientists usually obtain soil samples from crime scenes and suspected control sites from which soil may have been transported by shoes, a vehicle or a shovel. Soil properties are diverse and it is this diversity, which may enable forensic soil scientists to use soils with certainty as evidence in criminal and environmental investigations (e.g. see reviews by: Dawson *et al* 2008; Fitzpatrick 2008; 2009; Fitzpatrick *et al* 2008, Murray 2004; Murray and Tedrow 1991, 1975; Pye 2007; Ruffell and McKinley 2004).

In this chapter, consideration of a specific hit-and-run case described by Fitzpatrick *et al* (2007, 2008) highlights the kinds of investigations that have been carried out on highly complex Acid Sulfate Soil materials from shoes and a crime scene by the Centre for Australian Forensic Soil Science (CAFSS). The case example is described in a way that shows parallel approaches to more recent types of case investigations where soil as evidence are being applied with more certainty in criminal and environmental investigations. This hit-and-run case, which involves sulfidic material in an inland Acid Sulfate Soil, will be used as an example in this chapter to illustrate:

- the theory, significance and relevance of established concepts and standard terminologies used in forensic soil science,
- laboratory analytical techniques commonly used forensic soil science,
- systematic ways in which this information (e.g. soil morphology - e.g. colour, consistency, texture and structure, - mineralogy - powder X-ray diffraction, and chemistry (e.g. based upon infrared spectroscopy analyses) are used to distinguish between soils associated with forensic examinations which involves inland Acid Sulfate Soils,
- the ways in which this information can be applied advantageously in forensic casework.

HIT AND RUN CASE STUDY THROUGH A SUBAQUEOUS AND WATERLOGGED ACID SULFATE SOIL ALONG THE RIVER TORRENS

Background to case

This Hit and Run case involved two suspects that left the scene of a fatal car collision. One of the suspects was chased through the Adelaide suburbs at night and was later observed crossing the River Torrens. The suspect ran down the river bank, jumped into the river and onto the extended gravely and stony river bank (Figure 1(ii)) then proceeded up the opposite river bank before disappearing into the adjacent parklands. Figure 1 shows the area through which he is alleged to have run. The suspect was apprehended by police three hours later but denied ever running through this section of the river. As shown in Figure (2a) a small amount of fine yellowish-grey soil was strongly adhered to the side and in the treads of the sole from the suspect's shoes. A sufficient amount of the soil was recovered from the soles and sides of the shoes for forensic soil analyses by gently scraping the fine soil from the shoes using a plastic spatula (Figure 2b).

Figure 1: Map showing the River Torrens in the centre of the image where a Hit and Run offender ran from an adjacent Adelaide suburb, jumped into the River Torrens, crossed and then stepped on the river bank before running into the parklands. The two control samples of gravelly Acid Sulfate Soils (ASS) with sulfidic material from the alleged "crime trail' are located: (i) on the stony and gravelly bank (CAFSS_027.5) where the person is standing in the centre photograph and close-up view of the soil surface near where a shoe impression matching the sole tread of the shoe worn by the offender (Figure 2) was located by police (right hand side photograph) and (ii) in the river channel (subaqueous ASS; CAFSS 027.4). A sufficient amount of fine grained soil material was recovered from the control site samples by sieving the gravely (95% gravel and rock fragments with 5% clay and silt) samples through a 50 µm sieve (i.e. <50 µm fraction). Two additional "alibi samples" were collected from alibi trails or scenes (20 m upstream: CAFSS 027.3 and upper river bank: CAFSS 027) to determine whether or not the suspect had been along the alleged "crime trail'. (from Fitzpatrick *et al* 2008)

A control surface soil sample (0-3 cm) was taken where a shoe impression was located on the lower river bank (Figure 1 CAFSS 027.4) and where the suspect was seen to run (i.e. shoe imprint was similar to the sole tread of the shoe worn by the suspect). A second control soil sample (0-5 cm) was taken beneath 10 cm of water in the river channel one meter from the control sample site on the lower rive bank. These two yellowish-grey to dark brownish-black samples are from Acid Sulfate Soils (ASS) with sulfidic material, which comprise a mixture of 95% coarse gravel and stone fragments and only 5% clay and silt (<50 µm fraction). Although the control ASS comprised 95% alluvial stone and coarse gravel with only 5% clay and silt, a sufficient amount of fine soil (<50 µm) was recovered by sieving. As shown in Figure 2 (e), this fine soil material closely resembles (colour and texture) the fine soil material that was tightly trapped in grooves and treads in the rubber sole of the suspect's shoe (Figure 2 b). Analyses of these two soil materials using soil morphological descriptors (e.g. Schoeneberger *et al* 2002; Munsell Soil Color Charts, 2000; Fitzpatrick *et al* 1999), microscopical, XRD and DRIFT methods indicated that the soil from the river bank and soil on the suspect's shoes were similar (see below).

Two alibi samples were collected on the surface (0-3 cm) of: (i) a gravelly hydromorphic soil on the lower river bank, 20 m upstream (CAFSS 027.3; one meter from the river edge) from the two control sites and (ii) a non-gravelly alluvial soil on the upper river bank (CAFSS 027.6; five meters from the river edge, to determine whether or not the suspect had run along the alleged crime trail shown in Figure 1 (soil analyses are not reported in this paper).

Figure 2. Contact traces of yellowish-grey soil on the side and in the treads of the sole of the suspect's shoes [(a) left hand side and middle] and sample scraped from the shoe [(b) right hand side). Control soil specimens from the river channel [(c) left hand side] and bank of river shown in Figure 1 [(d) middle], which both comprise mixtures of 95% coarse gravel and rock fragments and only 5% clay and silt (<50 µm fraction). Photograph of the <50 µm fraction separated from the stony river bank soil sample (d) by sieving through a 50 µm sieve [(e) right hand side]. (from Fitzpatrick *et al* 2008)

SOIL AS A POWERFUL CONTACT TRACE

This section is essentially a summary of several recent reviews (Fitzpatrick 2008, 2009) and case study examples (Fitzpatrick *et al* 2008).

Theory of transfer of materials from one surface to another as a result of contact

The transfer of trace evidence is governed by what has become known as the "The Locard Exchange Principle" (Chisum and Turvey 2000), which states: "Whenever two objects come into physical contact - an exchange of materials takes place." When two things come in contact, physical components will be exchanged. For example, the exchange can take the form of soil material from a location transferring to shoes of a person who walked through a particular area. These types of transfers are referred to as primary transfers. Once a "trace material" has transferred, any subsequent movements of that material, in this case from shoes are referred to as secondary transfers. These secondary transfer materials can also be significant in evaluating the nature and source(s) of contact. Hence, the surface of soils can provide information linking persons to crime scenes.

Aardahl (2003) lists the properties of the ideal trace evidence: “(1) nearly invisible, (2) is highly individualistic, (3) has a high probability of transfer and retention, (4) can quickly be collected, separated and concentrated, (5) the merest traces are easily characterised, and (6) is able to have computerized database capacity.” In this context, Blackledge and Jones (2007), consider that glitter (i.e. entirely manmade tiny pieces of Al foil or plastic with vapour-deposited Al layer) may be the ideal contact trace. Soil materials may be considered as approaching the ideal “contact trace’, and the following brief discussion considers how closely they fulfil the criteria of Aardahl.

Soil is highly individualistic

The major question posed is how can soils be used to make accurate forensic comparisons when we know that soils are highly complex and that there are thousands of different soil types in existence? For example, according to the United States Department of Agriculture (USDA), which collects soil data at many different scales, there are over 50,000 different varieties of soil in the United States alone! Parent material, climate, organisms, and the amount of time it takes for these properties to interact will vary worldwide.

The following key issues are especially important in forensic soil examination because the diversity of soil strongly depends on topography and climate, together with anthropogenic contaminants:

Forensic soil examination can be complex because of the diversity and in-homogeneity of soil samples. However, such diversity and complexity enables forensic examiners to distinguish between soil samples, which may appear similar to the untrained observer.

Soil has a high probability of transfer and retention

In general, soil usually has a strong capacity to transfer and stick, especially the fine fractions in soils (clay and silt size fractions) and organic matter. The larger quartz particles (e.g. > 2mm size fractions) have poor retention on clothes and shoes and carpets. Fine soil material (e.g. their <50-100 µm fractions) may often only occur in small quantities, as illustrated in a Hit and Run case illustrated in this chapter (Figures 1 and 2; Fitzpatrick *et al*. 2007), where a remarkably small amount of fine soil was transferred from a gravelly and stony soil on a river bank (control site) to running shoes (forensic evidence items).

Soil can quickly be collected, separated and concentrated

Although a suspect may be unaware that soil material – especially the fine fraction - has been transferred directly to the person (e.g. shoes) or surroundings, soil materials are easily located and collected when inspecting crime scenes or examining items of physical evidence (e.g. Figures 1 and 2). Traces of soil particles can easily and quickly be located directly using hand lenses or light microscopes.

Soil samples must be carefully collected and handled at the crime scene or control sites using the established approaches and then compared by a soil scientist with forensic science experience to ensure that the soil samples can be useful during an investigation. The size and type of samples to be taken are strongly dependent on the nature of the environment being investigated, especially the type of soil and nature of activity that may have taken place at the scene (e.g. if suspect footwear is heavily coated with mud on the uppers and the ground is wet and soft then the control sample should be collected to a depth of around 0 to 10 cm; e.g. Figures 1 and 2). Subaqueous soils from the bottom of river channels, streams, ponds, lakes or dams can be obtained by pressing a plastic tube or container into the bed and removing it with a scooping action. In deeper water, samples can be taken using specialized sampling devices such as the Russian D-auger. If the soil is very hard and dry; and only the shoe tread was in contact with the soil, then collect the 0 to 0.5 cm – or thinner.

Several standard methods are available for quick separation and concentration of soil materials or particles such as for example sieving (e.g. described and used in Figure 2), magnetic extraction and heavy mineral separation (e.g. Figure 3).

Soil is nearly invisible
As described in the hit-run case study in Figures 1 and 2, under typical viewing conditions by the naked eye we do not really see the yellow-brown colour of the fine 5% clay and silt (<50 µm fraction) fractions hidden in the gravelly soil [Figure 2 (d)] until the sample is sieved and the fine fraction concentrated [Figure 2 (d) and (e)]. This is for example, often unlike the more obvious bright transfer colours of blood, lipstick smears and paint. Hence, not being obviously aware of the presence of fine soil materials, especially when they impregnate vehicle carpeting, shoes or clothing, a suspect will often make little effort to remove soil materials.

Computerised Soil Databases: Capacity
Soil profiles and their horizons usually change across landscapes, and also change with depth in a soil at one location. In fact, soil samples taken at the surface may have entirely different characteristics and appearances from soil dug deeper in the soil profile. One common reason why soil horizons are different at depth is because there is mixing of organic material, in the upper horizons, and weathering and leaching, in the lower horizons.

Easy to characterise soil materials: Large and trace amounts
Soil morphological descriptions follow strict conventions whereby a standard array of data is described in a sequence, and each term is defined according to both the USDA Field book for describing and sampling soils, Version 2.0 (Schoeneberger *et al* 2002) and National standard systems (e.g. Australian Soil and Land Survey Field Handbook by McDonald *et al* 1990). Soil morphological descriptors such as colour, consistency, structure, texture, segregations/coarse fragments (charcoal, ironstone or carbonates) and abundance of roots/pores are the most useful properties to aid the identification of soil materials (e.g. Fitzpatrick *et al* 2003) and to assess practical soil conditions (e.g. Fitzpatrick *et al* 1999).

Examples of several standard methods and results from various analytical methods used in forensic soil examination will be discussed below – e.g. see also several reviews covering mainly “forensic geology” by several workers (Murray 2004; Pye 2007; Dawson *et al* 2008; Ruffell and McKinley 2004).

COMMON AND STANDARDIZED TECHNIQUES USED BY FORENSIC SOIL SCIENTISTS

Evaluation of degree of similarity between questioned samples and control soil samples
It is important to first define the word “compare” because no two physical objects can ever, in a theoretical sense, be the same (Murray and Tedrow 1991). Similarly, a sample of soil or any other earth material cannot be said, in the absolute sense, to have come from the same single place. However, according to Murray and Tedrow (1991) it is possible to establish “with a high degree of probability that a sample was or was not derived from a given place”. For example, a portion of the soil (or other earth material) could have been removed to another location during human activity. Pye (2007) summarises different schemes commonly used by various members of the Forensic Science Service to convey weight of evidence relating to forms of comparisons such as trace or DNA evidence. For example, he has developed a “verbal categories” ranging from 0 (no scientific evidence) to 10 (conclusive) – with no statistical significance of the ranks implied. He also states that there is a long history of the use of numerical scales in the context of evidential and legal matters.

APPROACHES AND METHODS FOR MAKING COMPARISONS BETWEEN SOIL SAMPLES

Forensic soil scientists must first determine if uncommon and unusual particles, or unusual combinations of particles, occur in the soil samples and must then compare them with similar soil in a known location. To do this properly, the soil must be systematically described and characterised using standard soil testing methods to deduce whether a soil sample can be used as evidence (Figure 3). This systematic approach for forensic soil examination is outlined in several recent papers (Fitzpatrick 2009; Fitzpatrick *et al* 2008), which combines soil morphology (e.g. colour, consistency, texture and structure), mineralogy (powder X-ray diffraction), chemistry (e.g. based upon infrared spectroscopy analyses), biology and spatial field mapping information.

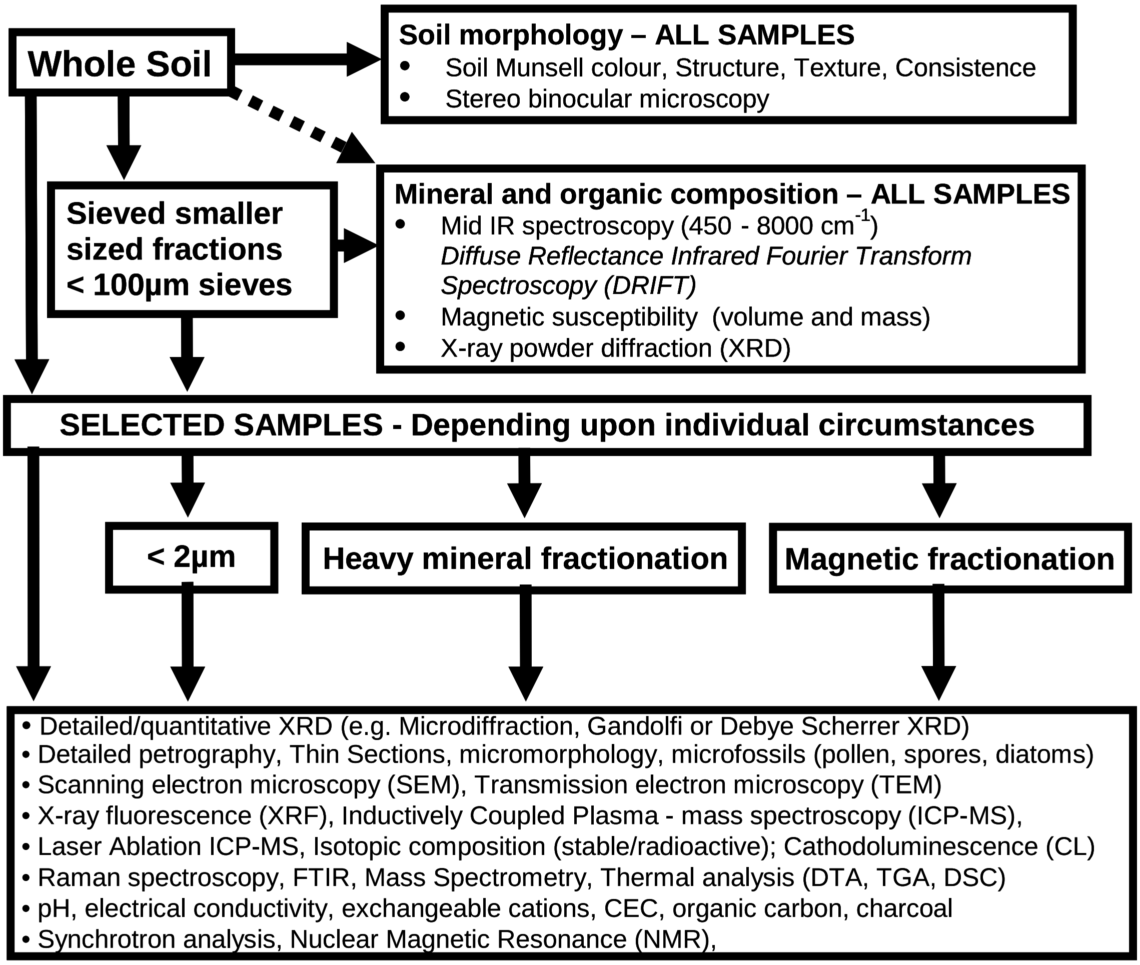

Figure 3. A systematic approach to discriminate soils for forensic soil examinations where, , FTIR is Fourier Transform Infrared spectroscopy, DTA is Differential Thermal Analysis, TGA is Thermogravimetric Analysis, DSC is Differential Scanning Calorimetry and CEC is Cation Exchange Capacity (modified from Fitzpatrick *et al* 2006; Fitzpatrick *et al* 2008).

These methods are applied in three stages:

- Rapid characterisation of composite soil particles in whole soil samples for the quick screening of samples (Stage 1)
- Detailed characterisation and quantification of composite and individual soil particles following sample selection, size fractionation and detailed mineralogical and organic matter analyses using advanced analytical methods (Stage 2)
- Integration and extrapolation of soil information from one scale to next, to build a coherent model of soil information from microscopic observations to the landscape scale (Stage 3).

This combined information is used for geographic sourcing to identify the origin of a crime scene soil sample by placing constraints on the environment from which the sample originated.

FORENSIC APPLICATIONS

The following soil analyses methods were required in this hit-run case, which was briefly outlined above. The first step was to visually compare the questioned soil samples from the suspect's shoes (i.e. adhered soil scraped from the soles and sides of the running shoes shown in Figure 2) and control samples (i.e. soils shown in Figures 1 and 2). The control samples were obtained from sulfidic material (Soil Survey Staff 1999) in the subaqueous Acid Sulfate Soils located both in the river and on the river bank where the suspect was seen to run and left a shoe impression, which was similar to the sole tread of the shoe worn by the suspect.

The visual comparison of the questioned samples from the shoe and control samples after sieving to obtain fine fractions (<50 µm) was conducted by eye and by low power stereo-binocular light microscopy. From these visual observations, it appeared that the fine fractions (<50 µm) from sulfidic material in the Acid Sulfate Soils in both the river bank and in the channel samples had a similar yellow colour to the soil adhered to the shoe (Munsell Soil Color Charts 2000). Consequently, because the river bank sample contained over 95% coarse gravel and stones, a sub-sample was sieved using a 50µm sieve to obtain a finer fraction (<50 µm). The fine soil fraction from the river bank and soil on the shoe had a remarkably similar colour (Munsell Soil Color) and mass magnetic susceptibility. Hence, in accordance with the systematic approach outlined in Figure 3, the third step was to check their mineralogical and chemical composition by using XRD and DRIFT analyses.

The XRD patterns - that can be likened to finger print comparisons- of the shoe (suspect) and ASS river bank (control) soil samples closely relate to each other (Figure 4). However, what is the significance of this close similarity in XRD patterns to the degree of similarity in terms of mineralogical composition? If the two soil samples, for example, contain only one crystalline component such as quartz (i.e. silicon dioxide), which is very common in soils, the significance of the similarity and its evidential value in terms of comparison criteria will be low. If, however, the two soils contain four or five crystalline mineral components, some of them unusual, then the degree of similarity will be considered to be high. In both cases, it was possible to evaluate the mineralogical data and formulate an opinion regarding the significance of the results obtained. The mineralogical compositions of the two samples are summarised in Table 1 and have a high degree of similarity because they both contain quartz, mica, albite, orthoclase, dolomite, chlorite, calcite, amphibole and kaolin. Relative proportions of the minerals are slightly different, likely due to the different distributions of particle sizes of the samples.

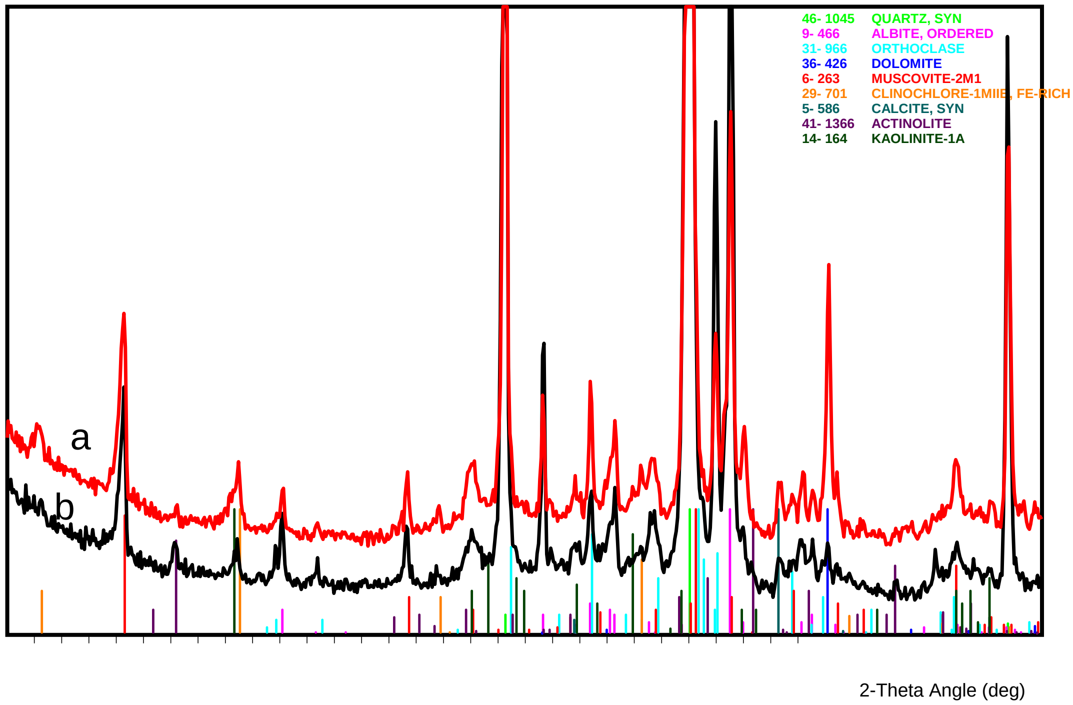

Figure 4. Comparisons between X-ray diffraction (XRD) patterns of soil samples from the shoe (b) and river bank (<50µm fraction) (a) shown in Figures 1 and 2. The <50 µm fraction was separated from the stony river bank soil by sieving through a 50 µm sieve. Shoe and river bank samples were both ground using an agate mortar and pestle before being lightly pressed into aluminium sample holders for XRD analysis. XRD patterns were recorded with a Philips PW1800 microprocessor-controlled diffractometer using Co K radiation, variable divergence slit, and graphite monochromator (from Fitzpatrick *et al* 2007).

Table 1. Summary of mineralogical composition from XRD analysis (from Fitzpatrick *et al* 2007; 2008).

Soil samples	Quartz	Mica	Albite	Orthoclase	Dolomite	Chlorite	Calcite	Amphibole	Kaolin
[1]River Bank	D	SD	M	M	M	T	T	T	T
[2]Shoe	D	M	M	M	T	T	T	T	T

Where:
[1]River bank sample (LRJ-1/ CAFSS 027.5) was sieved (<50µm fraction).
[2]Shoe sample (CAFSS 027.0) was not sieved (i.e. approximately <50µm).
D-Dominant (>60%), SD–Sub-Dominant (20-60%), M-Minor (5-20%), T-Trace (<5%).

DRIFT analysis was conducted on the same samples after XRD analyses (Fitzpatrick *et al* 2007). Electromagnetic energy in the mid-infrared range (4000-500 cm^{-1}) is focused on the surface of the air-dried, finely ground soil samples (using an agate mortar). Some of the beam penetrates a small distance into the sample and is reflected back into the spectrometer where the spectrum is collected, the spectra are expressed in absorbance (A) units (where A = Log 1/Reflectance). Whilst the two samples are spectrally similar (Figure 5) they do differ slightly in the amount of aliphatic organic matter (Table 2), which is reflected in peaks centered on 2850 and 2930 cm^{-1} (i.e. because the shoe sample has a slightly higher organic carbon content). They are very similar with regards to clay mineralogy (kaolinite clay 3690-3620 cm^{-1}) and the amount of quartz (2000-1650cm^{-1}) in the samples. A peak around 2520cm^{-1} also indicates the presence of a small amount of carbonate in both samples, with marginally more in the bank sample. These comparisons indicate that the two samples have a high degree similarity and most likely to have been derived from the same general location. In contrast, there is a lower degree of similarity with the two alibi soils samples (data not shown in Figure 1) and briefly described above.

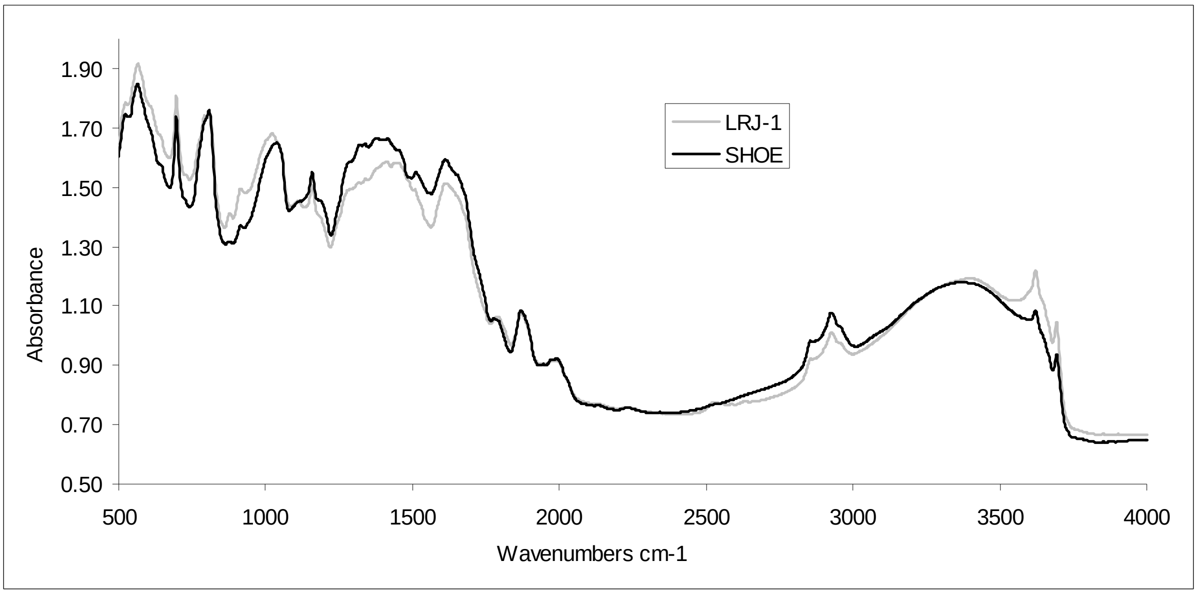

Figure 5. Comparison of Diffuse Reflectance Infrared Fourier Transform (DRIFT) spectra between the yellow-brown soil on the shoe (black tone) and the <50µm fraction in the stony soil from the river bank (grey tone). Shoe and river bank samples were both ground using an agate mortar and pestle (from Fitzpatrick *et al*. 2007).

Table 2. Predictions of charcoal (char), total organic carbon (TOC), pH (CaCl2), calcium carbonate (CaCO3), cation exchange capacity (CEC), clay, silt and sand contents from MIR-PLS analysis (Janik *et al* 1998).

Sample CAFSS	Char	TOC	pH $CaCl_2$	$CaCO_3$ %	CEC	Clay	Silt	Sand
	%	%		%	meq/100g	%	%	%
[1]Shoe 027.0	0.2	6.1	4.9	1.5	17	6	27	68
[2]River Bank 027.5 Lrj-1	0.2	3.4	5.5	4.6	15	12	35	53

Where:
[1]Shoe sample not sieved because it was already fine (i.e. approximately <50µm).
[2]The River bank was sieved <50µm fraction (Lrj-1/ CAFSS027.5).

To conclude, sufficient soil morphological, mineralogical (XRD) and physicochemical (DRIFT and MIR-PLS) data was acquired on the two samples to be able to determine if they “compare” or “do not compare”. The soil from the shoe has a high degree of morphological, chemical and mineralogical similarity to the fine fraction (<50µm) contained in the stony / gravelly soil on the river bank and in the river. Hence, the soil from the shoe is most likely sourced from the stony/gravelly soil on the river bank and in the river. Partly as a result of these analyses, the suspect was subsequently found guilty of ‘Hit and Run’ in the supreme court of South Australia.

SUMMARY AND CONCLUSIONS

The crime scene example described in this chapter uses combined pedological (including field investigations), mineralogical and spectroscopic methods in the forensic comparison of small amounts of soil adhering to a suspect’s shoe with control soil specimens from an inland subaqueous and waterlogged Acid Sulfate Soil (ASS) in the Torrens River and on its banks where a Hit-Run offender ran through. This case example illustrates that forensic soil examination can be very complex because of the diversity and heterogeneity of the soil samples involved. Although the ASS comprised 95% alluvial stone and coarse gravel with only 5% clay and silt, a sufficient amount of fine material (<50 µm) was recovered by sieving. This fine soil material closely resembled the fine soil material that was tightly trapped in grooves and treads in the rubber sole of the suspect’s shoe. Analyses of the two soil materials using visual, microscopical, XRD and DRIFT methods indicated that the soil from the river bank and soil on the suspect's shoes were similar. Such diversity and complexity of soil materials enables forensic soil examiners to distinguish between soils. The interpretation of soil forensic tests and methods is not equally applicable to all soils and should also be made in the context of the forensic soil examination (e.g. the sieving of large amounts of stone and gravel from ASS samples to obtain a more representative sample to make comparisons).

Soil materials are routinely encountered as evidence by police (physical evidence branch) for crime scene investigators and forensic staff. However, most forensic and physical evidence laboratories either do not accept or are unable to adequately characterise soil materials. The main reason for this is that morphological, mineralogical and spectroscopic analytical knowledge required to examine and interpret such soil evidence needs a large amount of training and expertise.

There is a general lack of expertise in this relatively new area among soil scientists. For research and practical application in this area to grow appreciably, it will need to be considered and taught as an integral part of both soil science and forensic science courses. Finally, according to Fitzpatrick *et al* (2008) an attempt should be made to develop and refine methodologies and approaches to develop a practical “Soil forensic manual with soil kit for sampling, describing and interpreting soils”.

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